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Linkage Control Security Research of the Mechanical Smoke Exhaust System in Large Space Buildings

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Abstract

When the large space buildings are in the event of fire, the mechanical smoke exhaust system must start safely and reliably with the smoke spreading quickly. A former analysis to the linkage control of the mechanical smoke exhaust system showed that the control of exhaust fans is safe and reliable with multiple redundant control， but the control security of exhaust ports in the large space buildings is very poor. According to the recent research, reliability of the linkage control of exhaust ports set in large space areas is the key to improve the reliability of the exhaust system's linkage control in large space buildings. We should set on-site mechanical control devices, remote multiple manual direct control devices and on-site electric control switch devices for exhaust ports in large space buildings. And the linked switches of exhaust ports should also be able to multiple interlocks control the exhaust fans.

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Keywords: large space buildings; mechanical smoke exhaust system; exhaust fan; exhaust port; linkage control; security

1. Introduction

When the large space buildings are in the event of fire, fire and smoke spread rapidly. It's necessary to exhaust the smoke as soon as possible for the safety of people evacuation and fire extinction. The mechanical smoke exhaust system in buildings consist of exhaust fans, exhaust ports or valves, exhaust vertical shafts and their control devices. In case of fire, the exhaust fans start and the exhaust ports or valves in the fire area open. In practical engineering applications, the control security of exhaust ports and valves is poor, and there are also some hidden faults in the linkage control between exhaust fans and exhaust ports or valves. In this paper, an in-depth research to the linkage control security of the mechanical exhaust system in large space buildings has been made and a mechanical exhaust linkage control system with high security has been established.

2. Control of exhaust fans

The exhaust fans may be centrifugal fans or axial flow fans, which are the key devices in the mechanical exhaust system. If the bus module control is used in the system, a manual direct control device must be set in the fire control room in order to ensure the security and reliable of the fans［1］. The control mode of exhaust fans is shown in Fig.1.

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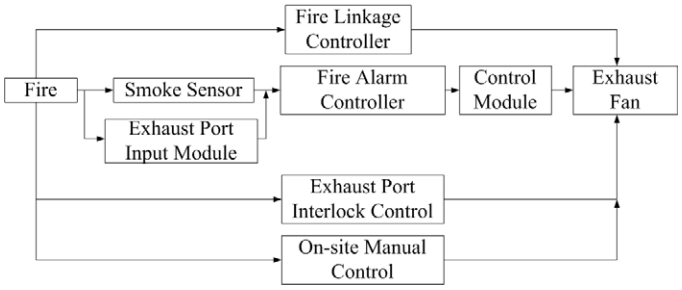

Fig.1 control mode of exhaust fans

2.1. Bus module control

Fire alarm controller controls exhaust fans by the bus control module.

2.2. Multi-line direct control

The multi-line linkage controller in fire control center can control exhaust fans manually and directly.

2.3. Linkage control of exhaust ports

Exhaust ports are interlocked with exhaust fans. The fans would start automatically if any exhaust port is open [2] [3]. Linkage control between exhaust ports and fans is divided into hard interlock control and soft interlock control. Hard interlock control is achieved by connecting exhaust ports linkage switch with fans in the control cabinet. On the other hand, soft interlock means that the fans are controlled by fire alarm controller with exhaust ports action signal and bus control modules.

2.4. On-site manual control

Users can control exhaust fans manually by the start/stop button in the on-site control cabinet.

3. Control of exhaust ports

Exhaust ports are set by the smoke prevention compartments. Exhaust ports are usually installed in the beginning of exhaust pipe which are located on the ceiling or the wall nearby. The ports are closed ordinarily with manual and automatic start devices installed [2] [3]. Smoke in the fire zone would be inhaled into the branch pipes by exhaust ports, be converged into the exhaust system's main pipe, and finally be poured outside of the building by exhaust fans. Control mode of exhaust ports has been shown in Fig. 2.

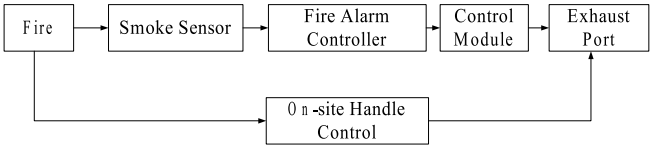

Fig. 2 control mode of exhaust ports

3.1. Bus module control

Spreading smoke in fire zone will make the smoke sensors alarm. The control module will be started by the fire alarm controller and smoke will be discharged from the exhaust ports.

3.2. On-site handle control

The evacuating people can also start the exhaust system by the on-site handle which has been set on the exhaust ports.

4. Analysis of linkage control

When the building is on fire, the exhaust fans must be linked with the exhaust ports and the control must be security and reliable. If there is any error appeared in the linkage control, for example, the fans start with the exhaust ports can not be opened, the ports has been opened but the fans can't be started, or both of them can't work normally, the building's mechanical exhaust system would not work well at all. All of these errors will lead to serious hidden dangers of security.

4.1. Analysis of exhaust fans control

There are too much segments in the bus module control of exhaust fans. If any one of them such as smoke sensors, alarming loop, fire alarm controllers and control modules has trouble in operating, the fans won't be controlled. Security of this control method is not enough.

There are no intermediate links in manual direct control and firemen can control the exhaust fans manually and directly in the fire control center by multiline. Manually direct control makes sure that firemen can start the exhaust fans in time when it’s on fire. It's very reliable.

Hard interlock direct control of exhaust ports has high security. On the contrary, soft interlock control refers to two systems such as mechanical exhaust system and fire automatic alarm system and has lower security.

It's very reliable to control the fans by the start/stop button which has been set in the on-site exhaust fans control cabinet. But when there is on fire, considering the influence of smoke and high temperature, it's almost impossible for firemen to walk into the exhaust fans room and start the fans manually.

4.2. Analysis of exhaust ports control

It's necessary to control the exhaust ports reliably when there is on fire. Even the exhaust fans have been started, if exhaust ports in the fire zones can't be opened efficiently, the smoke will not be poured out in time and the people in evacuation will be still surrounded by a great deal of smoke.

Bus module control is the main control method with too many necessary links and low security.

It's difficult for the on-site handle to open the exhaust ports which has been installed on the ceiling in the fire. There's lots of smoke surrounding the exhaust ports that need to be opened. It's impossible to reach the ceiling without a ladder or other tools. And the worker must know the exact location of exhaust ports and be skillful enough to open the ports. Hence security by opening the exhaust ports installed on ceiling with on-site handle is very poor.

5. Security research to the linkage control systems

According to the above analysis， the control of exhaust ports and fans is security and reliable by using multiple redundant control to exhaust fans. But the control of exhaust ports in large space areas is not so security that the security of whole mechanical exhaust systems has been regarded as poor. Linkage control logic relationship of the mechanical exhaust systems is shown in Fig. 3.

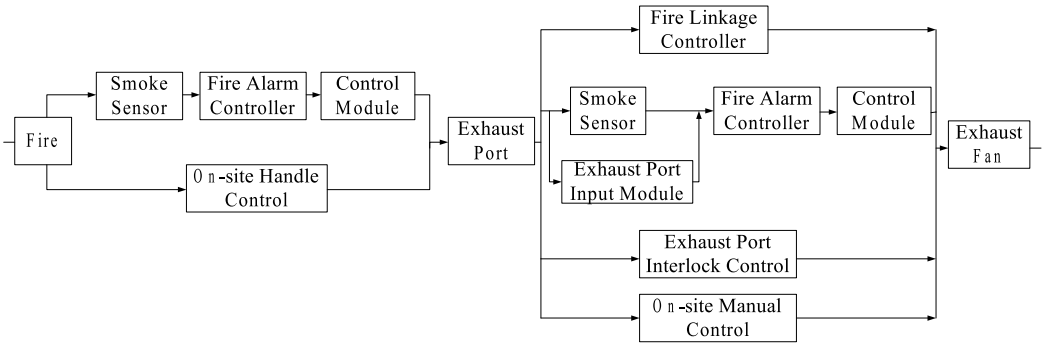

Fig. 3 linkage control logic relationship of the mechanical exhaust systems

Set reliability of each unit equal to R, the system's reliability ($R_{S1}(t)$) is:

$$R_{S1}(t)=\left[1-\left(1-R^3\right)\left(1-R\right)\right]\cdot\left\{1-\left\langle 1-\left[1-\left(1-R\right)^2\right]\cdot R^2\right\rangle\cdot\left(1-R\right)^3\right\}\cdot R^2 \tag{1}$$

In order to improve the security and reliability of mechanical exhaust systems in large space buildings, it's necessary to improve control security and reliability of the exhaust ports which has been set in large space areas. Specific measures are described as the follows.

(1) Change the on-site handle control of exhaust ports in large space areas into on-site mechanical control device. The new mechanical control device is installed on the wall or pillar apart from the ground 1.5 meters high near the exhaust ports of large space areas. People can operate the device easily without any tools.

(2) Add manually direct control to the exhaust ports in large space areas and firemen can multiple remote control the ports manually and directly in the fire control center. The control reliability will be improved by installing multiline linkage control for each exhaust port. But there are a large number of exhaust ports in the building, too much linkage control line will make linkage controller set in the fire control center too complicated. The multiple linkage control will be installed only for the ports which can't be controlled by on-site handle.

(3) Install on-site electric control device on the wall or pillar apart from the ground 1.5 meters high near the exhaust ports in large space areas. The ports can be opened by start button.

The linkage control logic relationship of the improved system is shown in Fig. 4. System Reliability ($R_{S2}(t)$) is:

$$R_{S2}(t)=\left[1-\left(1-R^3\right)\left(1-R\right)^3\right]\cdot\left\{1-\left\langle 1-\left[1-\left(1-R\right)^2\right]\cdot R^2\right\rangle\cdot\left(1-R\right)^3\right\}\cdot R^2 \tag{2}$$

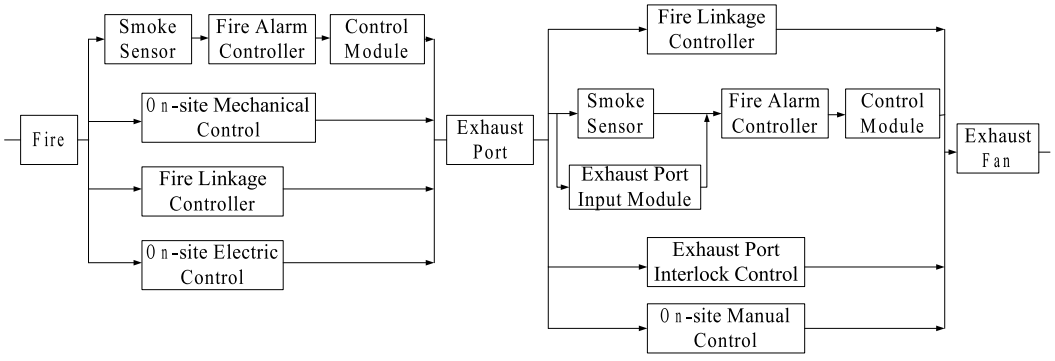

Fig. 4 linkage control logic relationship of the improved system

Simulation curves of the mechanical exhaust systems reliability($R_{S1}(t)$, $R_{S2}(t)$) in large space buildings are shown in Fig.5. We can see that the improved mechanical exhaust systems have higher security and reliablity.

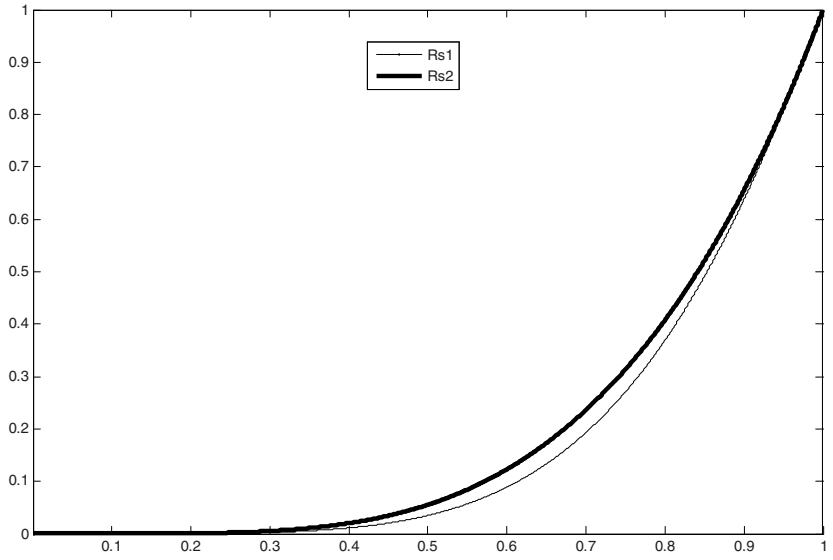

Fig. 5 simulation curves of the mechanical exhaust systems reliability in large space building

6. Conclusions

The linkage control security of exhaust ports installed in large space areas is vital to improve the security and reliability of mechanical exhaust systems by linkage control in large space buildings and it's always ignored in practice applications. The linkage control of exhaust ports in the large space areas should achieve the following requirements.

(1) Mechanical control device should be installed on the wall or pillar apart from the ground 1.5 meters high near the exhaust ports in large space areas.

(2) Multiline manually remote direct control device should be installed for the exhaust ports in large space areas.

(3) On-site electric button control device should be installed on the wall or pillar apart from the ground 1.5 meters high near the exhaust ports in large space areas.

(4) The exhaust ports linkage switch should be able to multiple interlock control the exhaust fans.

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